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Low-energy house in Sisimiut – Data overview

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Abstract

Experiments with persistently exciting heat inputs are a fundamental tool in identification of heat dynamics in buildings. The Low-energy house in Sisimiut, Greenland, provides an advanced experimental setup with frequent measurements of temperatures, heat inputs, and much more. This paper presents an overview of data collected since the installation of the new measurement and control system. Focus is on heat dynamics so only data related to that will be shown. 5 experiments have been conducted. They are described, and resulting data is shown.

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1 Introduction

A new data acquisition system was installed in a low-energy house in Sisimiut, Greenland, in April 2011. This is documented in Andersen et al. 2013b. Since then, two heating seasons have past. Here, a quick overview will be given of the data collected. Floor heating power is the main heat input in the building, and it is measured by different sensors.

For identification of heat dynamics of buildings, experiments that excite the dynamics are crucial. This can be achieved by designing the heat inputs with pseudo random binary signals (PRBS). This paper presents 5 experiments designed using PRBS signals. Three of the experiments are designed with the aim to model the apartment as one large room, using common heating signals in all rooms and open doors between them. Two experiments are designed with multi-room models in mind. They were both run with closed doors between the rooms and different floor heating inputs for each room. Moreover, in the last experiment a combination of floor heating and electric radiator heating is used. This enables separate models for the two heat sources which can provide valuable information about the floor heating system.

Data especially relevant for modeling heat dynamics of the building or of the guest apartment will be shown. Much more data is accessible as documented in Andersen et al. 2013b. Some of the data acquired before the installation of this new system was analyzed in Andersen et al. 2013a.

2 Overview of the collected data

This section presents a brief overview of the data that has been collected since the installation of the new measurement system. Here, a single measurement (the signal called A01_X02) for all the floor heating in the building will be plotted. For a common indoor temperature, a the room temperature measurements have been weighted by the surface areas of the rooms. Also outdoor temperature, solar radiation, and wind speed are plotted. All signals have been averaged to daily values. The data for the two periods is seen in Figures 1 and 2. Refer also to the nomenclature in Table 1.

The floor heating signal misses many data points. It is possible that the measurements on the floor heating loops in the individual rooms will give more information. However, notice that the sum of these normally exceeds the one plotted. They have to be scaled as argued in Andersen, Jiménez, et al. 2013.

2.1 Energy signatures

To get a quick idea of the energy signature of the building in the two periods, the following ARX model (Madsen 2008) has been fitted to

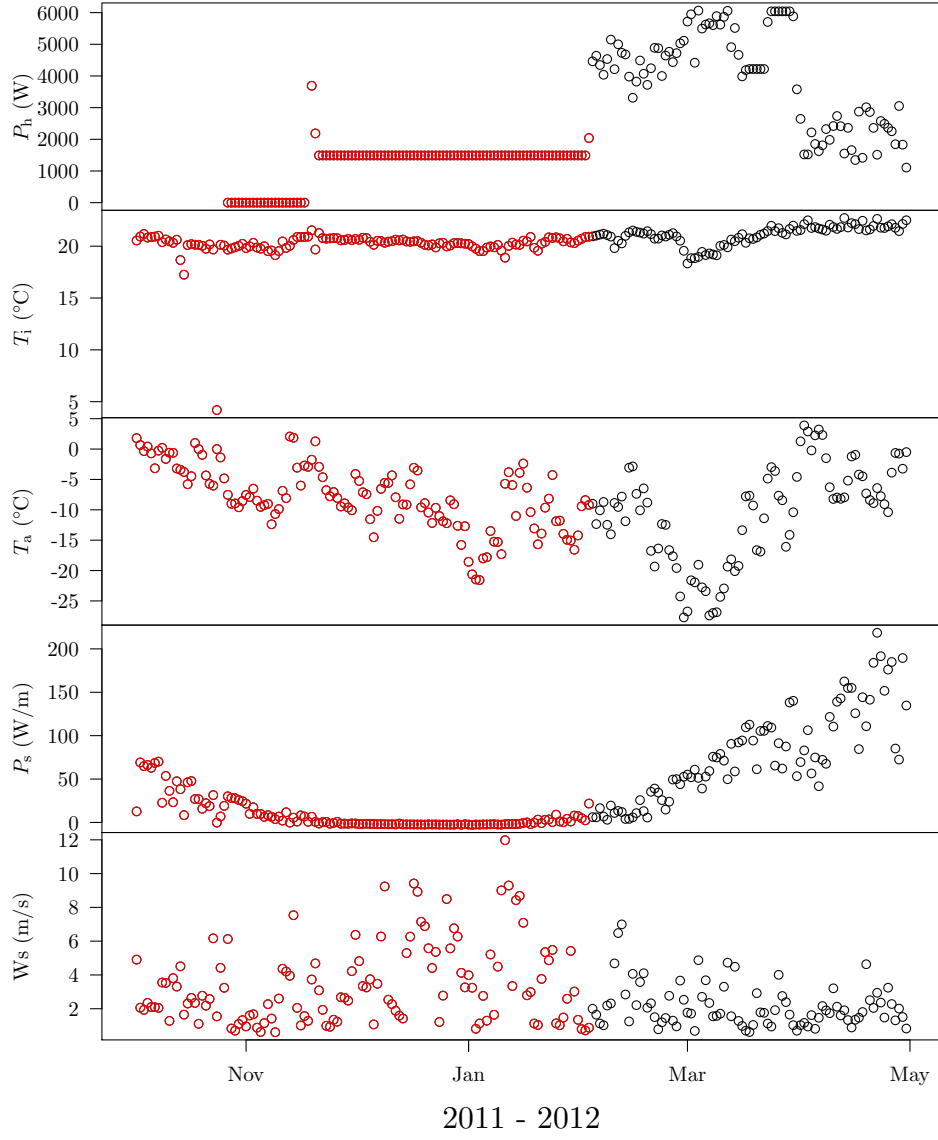


Figure 1 Data from the first heating season. The indoor temperature is an area-weighted average for the whole building.

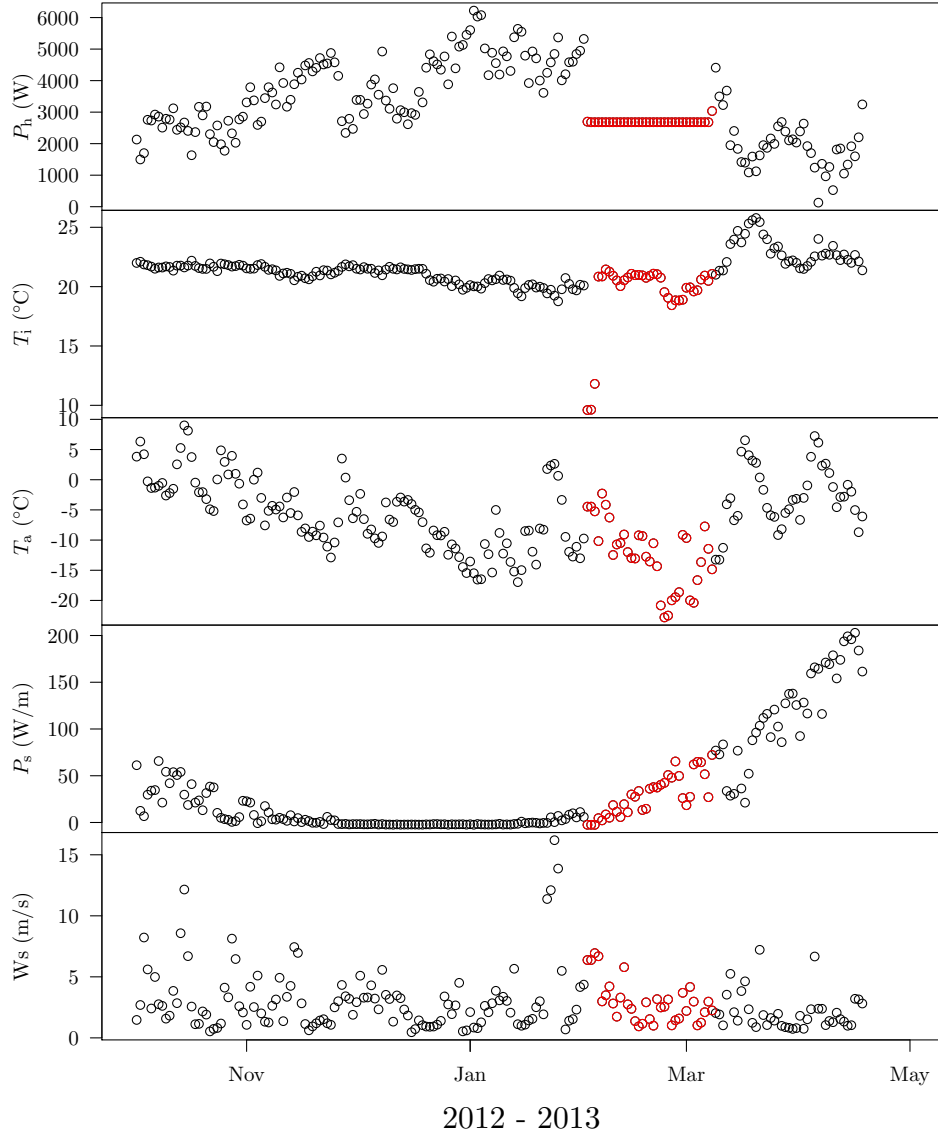


Figure 2 Data from the second heating season. The indoor temperature is an area-weighted average for the whole building.

Table 1 *Nomenclature*

| | |
|---------------------------|--|
| P_s (W/m ²) | Global horizontal solar radiation measured on weather station. |
| P_v (W) | Estimate of ventilation heating to one apartment. |
| T_a (°C) | Outdoor temperature measured on weather station. |
| T_i (°C) | Area weighted indoor temperature. In experiments, only for guest apartment. |
| P_h (W) | Floor heating. In experiments, it's the sum of the contributions to the rooms in the guest apartment. In the data overview, it's the total floor heating supply which is measured by another sensor. |
| W_s (m/s) | Wind speed measured on weather station. |
| y (°C) | Mean of temperature measurements in central column in Guest apartment. |

average daily values:

$$\begin{aligned}
P_h(n) = & P_h(n-1) + T_i(n) + T_i(n-1) \\
& + T_a(n) + T_a(n-1) + P_s(n) + e(n)
\end{aligned} \tag{1}$$

where P_h is floor heating, T_i is indoor room temperatures of the whole building weighted by area, T_a is outdoor temperature, P_s is global horizontal solar radiation, and n is the day number. $\{e(n)\}$ are i.i.d. following $N(0, \sigma^2)$. Table 2 contains derived physical parameter estimates using the same methods as in Andersen et al. 2013a.

Table 2 *Physical properties derived from Model 1.*

| | Period 1 | | Period 2 | |
|---------|----------|-------|----------|------|
| | est | std | est | std |
| UA, W/K | 145.79 | 16.54 | 141.78 | 6.36 |
| gA, – | 9.27 | 6.74 | 12.07 | 2.91 |

3 Conducted experiments

This section briefly describes and provides overviews of data obtained from the experiments carried out in the guest apartment in the period February 2012 – March 2013. Table 3 gives an overview of the 5 conducted experiments, their periods of execution, duration, if internal

Table 3 *Overview of the five conducted experiments. The two first are intended for estimation of properties on the whole apartment, the 3 others on each room separately. Moreover, the last experiment can be used to estimate heat capacity of the floor heating system*

| Exp | start | end | #days | doors | PRBS | radiators |
|-----|-------------|-------------|-------|--------|------|-----------|
| 1 | Feb 21 2012 | Mar 09 2012 | 16.6 | open | A | no |
| 2 | Jan 09 2013 | Jan 16 2013 | 7 | open | A | no |
| 3 | Jan 16 2013 | Feb 04 2013 | 18.2 | closed | B | no |
| 4 | Feb 22 2013 | Mar 10 2013 | 16.5 | closed | B | no |
| 5 | Mar 12 2013 | Mar 24 2013 | 12.6 | closed | C | yes |

doors have been open or closed, which PRBS signal has been used for floor heating, and if electric radiators have been used. The ventilation system has been controlled from measurements humidity or it has been shut off by the tenants of then rental apartment.

3.1 Experiment 1 – A single-room experiment

The aim of the experiment is estimation of thermal properties of the experimental apartment as a whole. For obtaining this, the floor heating inputs to all rooms are being varied together, and the dynamic thermal response of the house is being studied. All outer doors and windows of the apartment were kept closed, and all inner doors were kept wide open. This is to be able to model the envelope as well as possible without internal thermal resistances between rooms.

The experiment started on February 21 and finished on March 9, 2012. Plots of the obtained data are shown in Figure 3. (Andersen, Jiménez, et al. 2013) presents graybox modeling of this data set. Also, many of the examples in (Andersen et al. 2013b) are from this experiment.

To vary the floor heating with as wide a range of frequencies as possible and independently of other inputs, pseudo random binary signals (PRBS) were used (Godfrey 1980). To get as large an excitation of the system as possible, the floor heating was either completely off or at maximum power in accordance with the designed signal. The expected mean value of a PRBS is 0.5. this means that if such a signal is followed, the heating system will in average deliver half of its maximum power.

From simple experiments and rough calculations, it was seen that following a PRBS would give too little a heating input to keep the indoor temperature within normal operation temperatures (say 17°C-26°C) because the floor heating system was relatively small compared to the low outdoor temperatures. Therefore, after the PRBS were generated, the length of the heating periods were doubled.

The heating system has an experimental module where floor heating schedules can be implemented (documented in Andersen et al. 2013b).

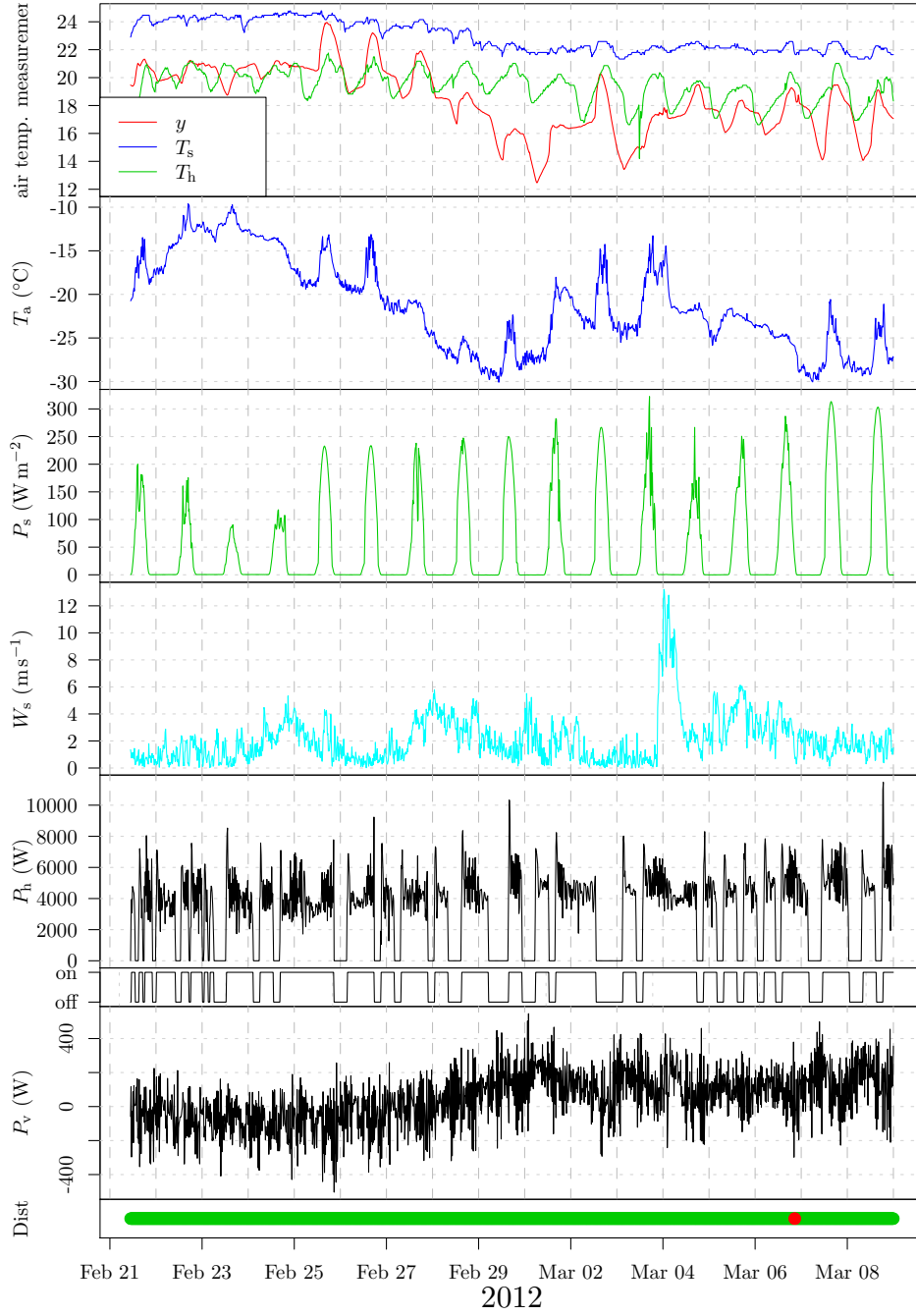


Figure 3 *The indoor air temperature together with temperatures in the scullery and entrance hall followed by weather data, heating signals, and a view of the incidences of disturbances of the experiment.*

It works with half hour steps so the PRBS are interpreted as one step per half hour. Also from rough calculations from initial experiments,

it was estimated that shifts after less than one hour with or without heating was unnecessary.

Three PRBS were generated. One of fast shifting regimes, and two of slower shifts. To generate a PRBS one has to choose the length of the register (n), the initial value of the register (R_0), and the shortest allowed length of a sub-sequence of zeros or ones (λ). The function used for the generation of the signals was written by Peder Bacher. After the generation of the PRBS signal and the scaling of the heating periods, the length of the signals did not match the wanted experiment duration. Hence, they were cut off to match the available time. Also the first signal was started at the second value instead of the first. The starting indexes and the length of the used sequences are listed together with the properties of the three signals in Table 4. Figure 4 shows the signals used, the three signals colored differently. There are no gaps between the signals. The same signal was shown in Figure 3.

Table 4 Options used for generation of the PRBS signals used in the design of Experiment 1.

| Signal | n | R_0 | λ | start | length |
|--------|-----|-------|-----------|-------|--------|
| 1 | 5 | 402 | 2 | 2 | 93 |
| 2 | 10 | 982 | 7 | 1 | 579 |
| 3 | 8 | 102 | 7 | 1 | 124 |

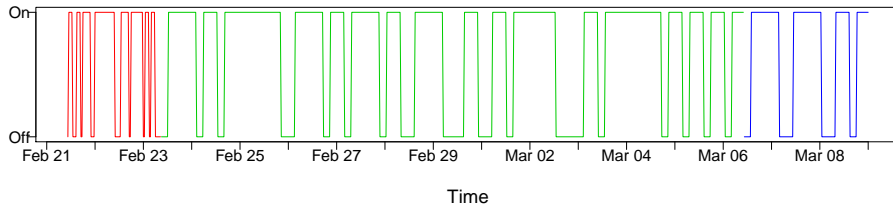


Figure 4 The PRBS signals used for Experiment 1.

3.2 Experiment 2 – repetition of Experiment 1

The second experiment repeats the floor heating signal from Experiment 1 starting on January 9 at 4:35:00 PM UTC and ending on January 16 at 6:08:00 AM UTC. The doors inside the apartment were kept open like in Experiment 1. Data is plotted in Figure 5. Before this experiment, a HOBO data logger was placed in the boiler room to measure the temperature every minute. This was in use during Experiment 2–5. This temperature measurement will be denoted T_b .

While there is considerably less solar radiation at this time of year, the outdoor temperature is higher during Experiment 2 than it was in Experiment 1. The indoor temperature stays within 15 and 21°C. The experiment seems to have been disturbed a couple of times.

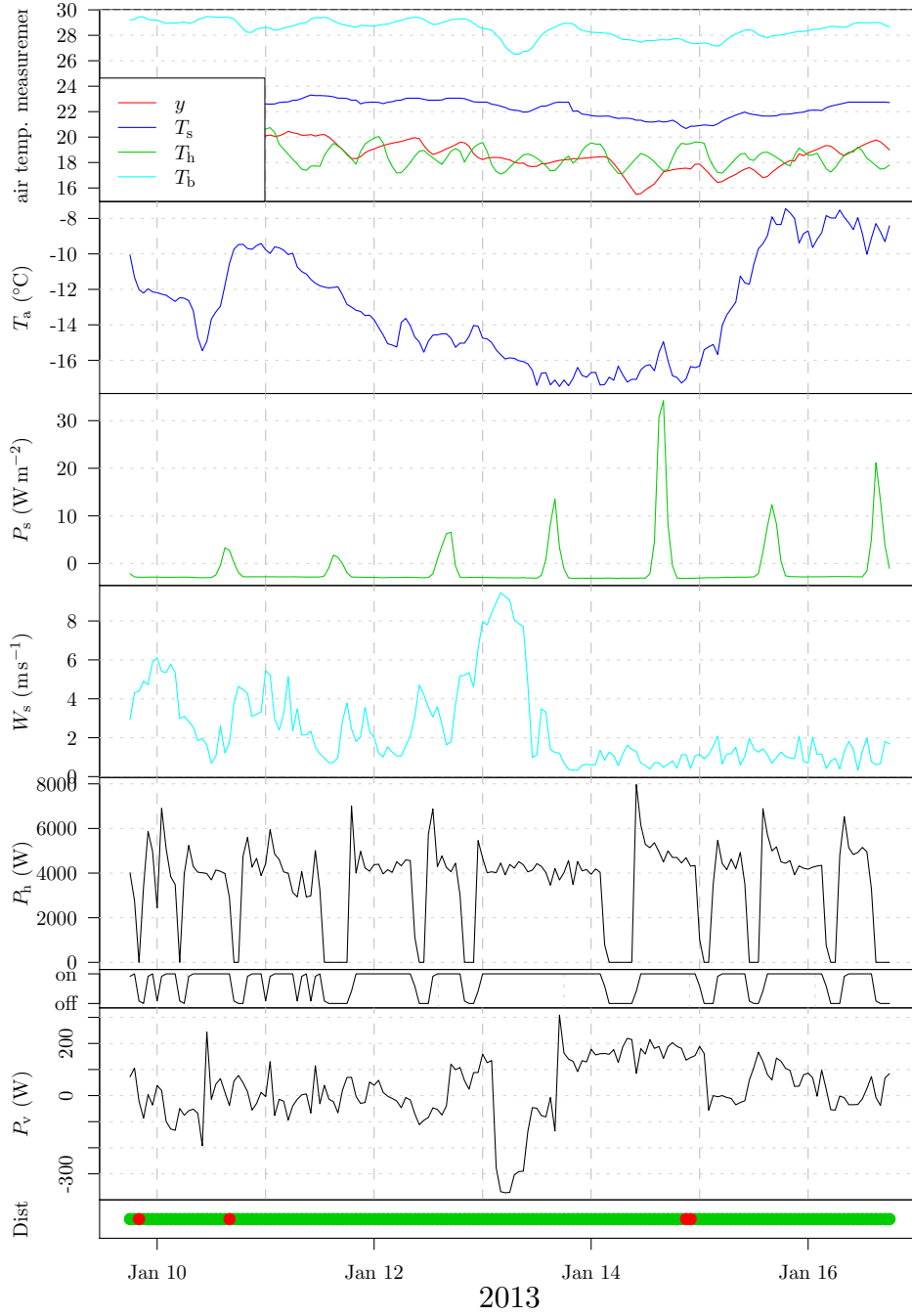


Figure 5 Mean temperature measured in the thermometer column, weather data, and heat input data for Experiment 2.

3.3 Experiment 3 – A multi-room experiment

The third experiment was carried out with closed doors between the rooms inside the apartment and with different PRBS signals controlling

the floor heating in each room.

The experiment was started on January 16 2013 at 8:11:00 PM UTC and ran until February 2 early in the morning. It was interrupted two times by opening of doors, and the last of these incidents was on February 1st at 11 AM UTC, where the data set can be cut. That will give about 15 days of data.

Figure 7 shows the temperatures and floor heating inputs for each of the rooms. All the temperature signals have many fluctuations, and the between-rooms temperature differences are quite large. Where the temperatures are between 13 and 20°C in the small, the large room, the corridor and the living room, the bathroom is significantly warmer – 21 to 27 °C. The bathroom has no cold walls, and it is neighboring the boiler room.

Table 5 *Options used for generation of the PRBS signals used in the design of Experiment 3.*

| Signal | n | R_0 | λ | start | length |
|--------|-----|-------|-----------|-------|--------|
| 1 | 8 | 322 | 2 | 1 | 144 |
| 2 | 11 | 322 | 7 | 1 | 1344 |

Table 5 provides an overview of how the PRBS signals used for Experiment 3 were created. Two different signals are used. One generating a relatively quickly alternating signal, one giving slower alternations. After creation of a long sequence, five sequences are taken out of this by stepping $\frac{2^n-1}{3}$ indexes every time. This ensures not to have cross correlated signals Godfrey 1980. Again after doing this, the individual signals were scaled by doubling the sequences of heating in order to maintain reasonable indoor temperatures during the experiment. The resulting heating signals are seen in Figure 7. The control signal is now fluctuating between 0 and 32. This is a binary representation of the signals in the different rooms. See Andersen et al. 2013b on experiment design for documentation of this.

Experiment 3 provides good data for fitting a model where the individual rooms are described by individual states. The heat exchange between the living room and the corridor may require special attention since they are not separated by walls or doors and because of the level difference between them.

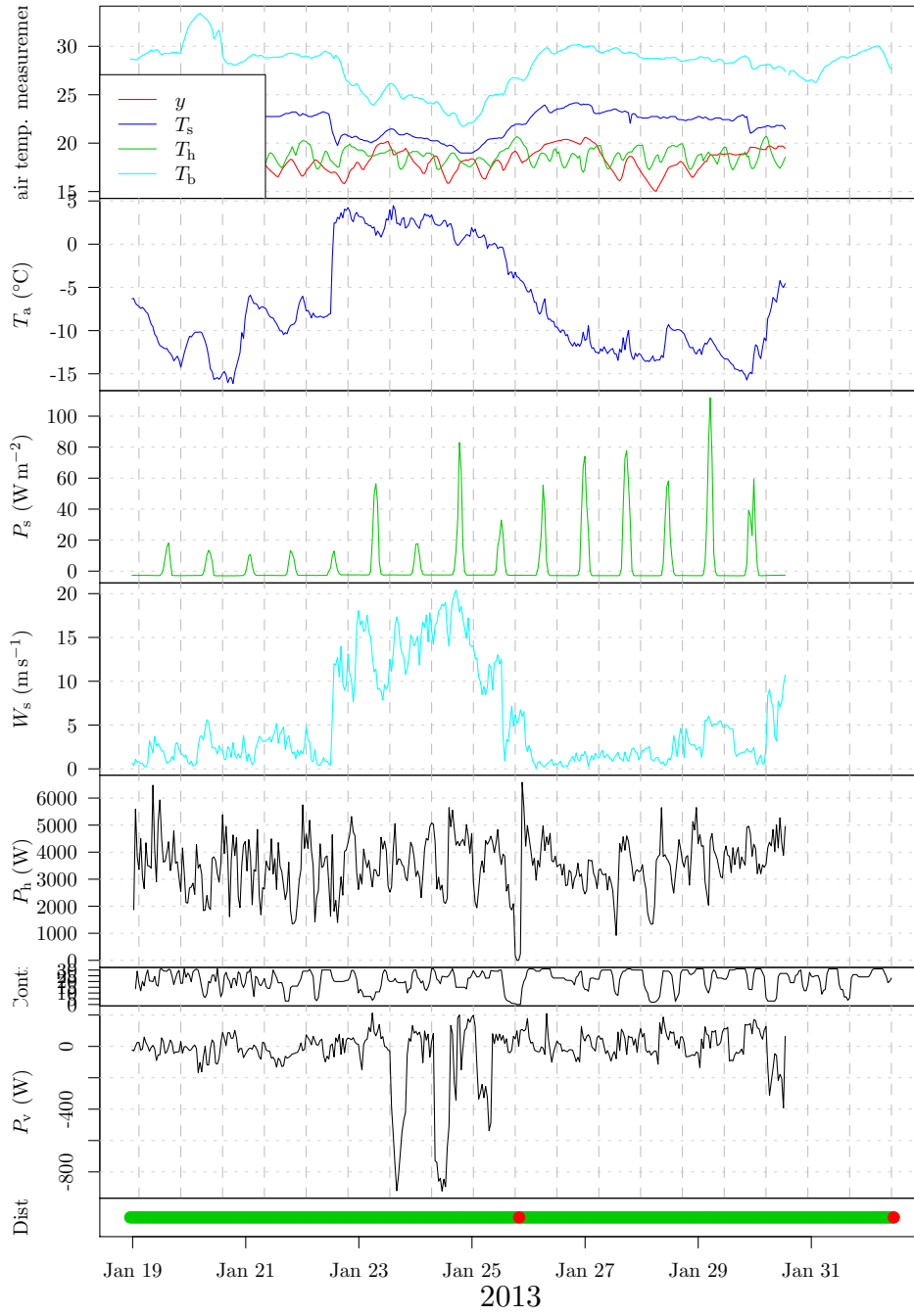


Figure 6 Mean temperature measurements, weather data, and heat input data for Experiment 3.

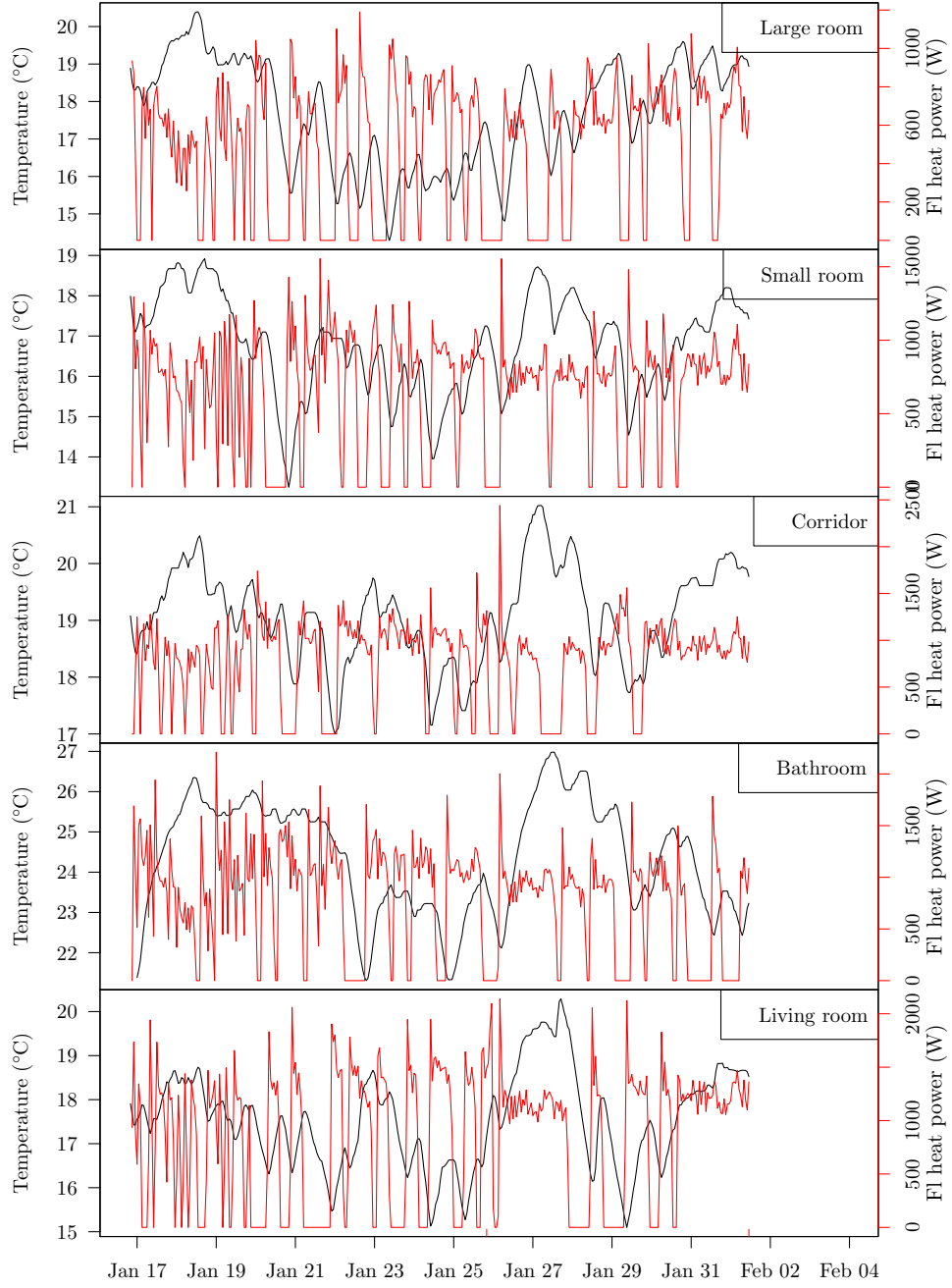


Figure 7 *The floor heating signals from Experiment 3.*

3.4 Experiment 4 – repetition of Experiment 1

This is a repetition of Experiment 1 at the same time of year – one year later. An overview of the obtained data is shown in Figure 8. The ventilation heating system seems to have been off most of the period. The experiment was start on February 22nd and ended on March 10th. However, from March 5th, a quite some disturbances are seen. Still it gives more than 11 days of data without disturbances.

Temperatures in the individual rooms and floor heating signals are plotted in Figure 9.

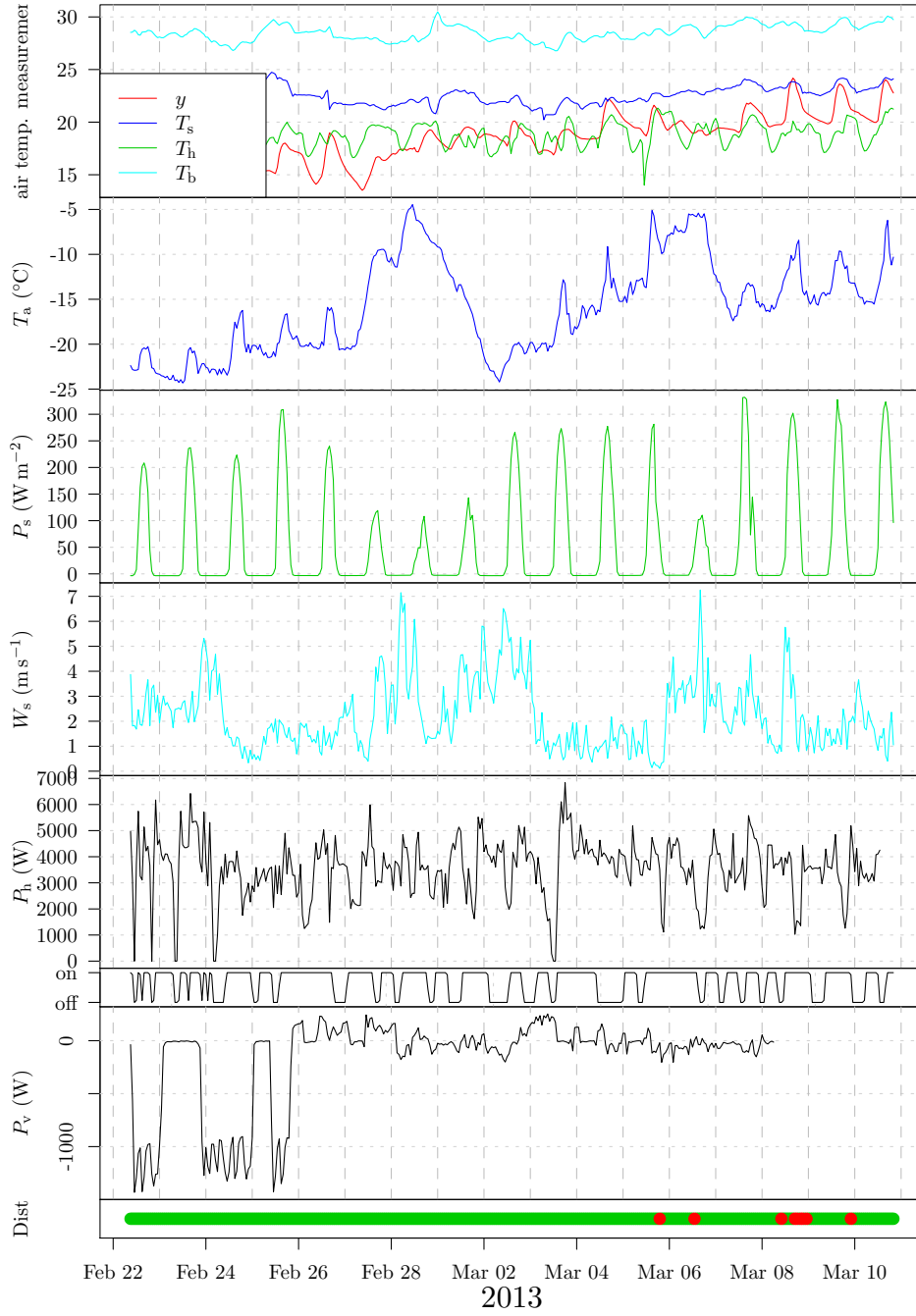


Figure 8 Overview of data from Experiment 4.

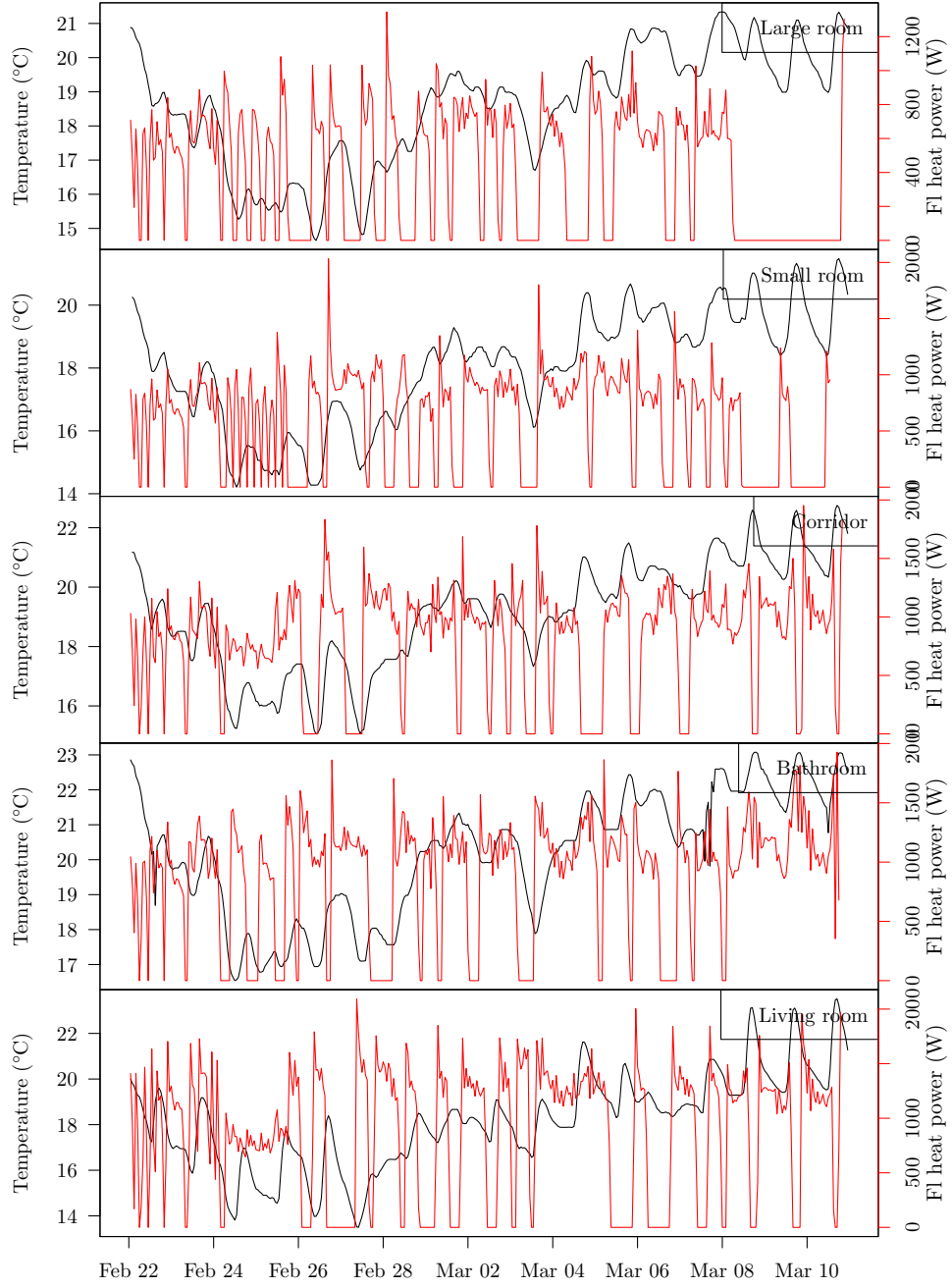


Figure 9 The floor heating signals from Experiment 4.

3.5 Experiment 5 – A multi-room experiment with electric radiators

Experiment 5 includes the use of radiators. This provides a heat input that can be assumed to be fully known. Whereas the floor heating power is estimated from flow and temperature measurements in the floor heating system, and calculations using assumed properties of the liquid in the floor heating system, the power supplied to the radiators have been measured directly.

Radiators of about 700 W each were placed in the middle of the small room, the large room, the corridor, and in the living room. They all followed different PRBS signals, uncorrelated with the floor heating signals.

Table 6 *Options used for generation of the PRBS signals used in the experimental design for the radiators in Experiment 5. The signals were programmed on digital timers so that index 1 starts on Monday at midnight on room 1.*

| Signal | n | R_0 | λ | start | length |
|--------|-----|-------|-----------|-------|--------|
| 1 | 6 | 85 | 2 | | |

The radiators followed PRBS signals generated as described in Table 6. The signal was made into 4 uncorrelated signals as described in Section 3.3.

The floor heating signals were scaled not to overheat the apartment. However, as seen from Figure 10, the temperatures of the two rooms reached 40°C which is the limit of the measurement range of the thermal sensors. For this reason, these two radiators were turned off during the experiment (leading to disturbance of the experiment). However, the data can still be used if only the (output) points of temperatures of 40°C are removed.

The ventilation seems to have been turned off the whole period. Moreover, there are many interruptions of the experiment.

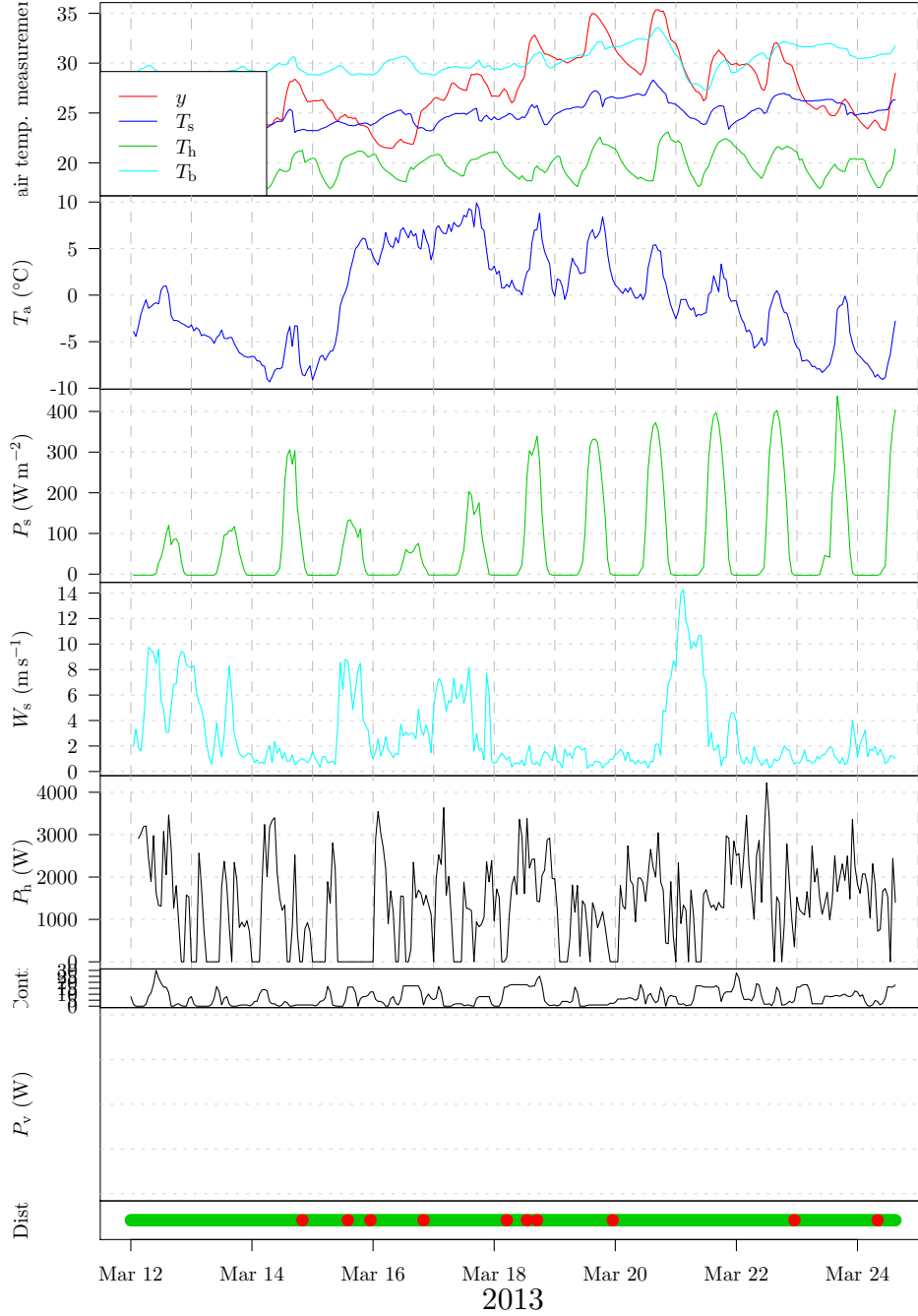


Figure 10 Indoor air temperature, weather measurements, and total heating for Experiment 5. Ventilation heating was turned off by the inhabitants of the building. Moreover, the experiment has been interrupted several times.

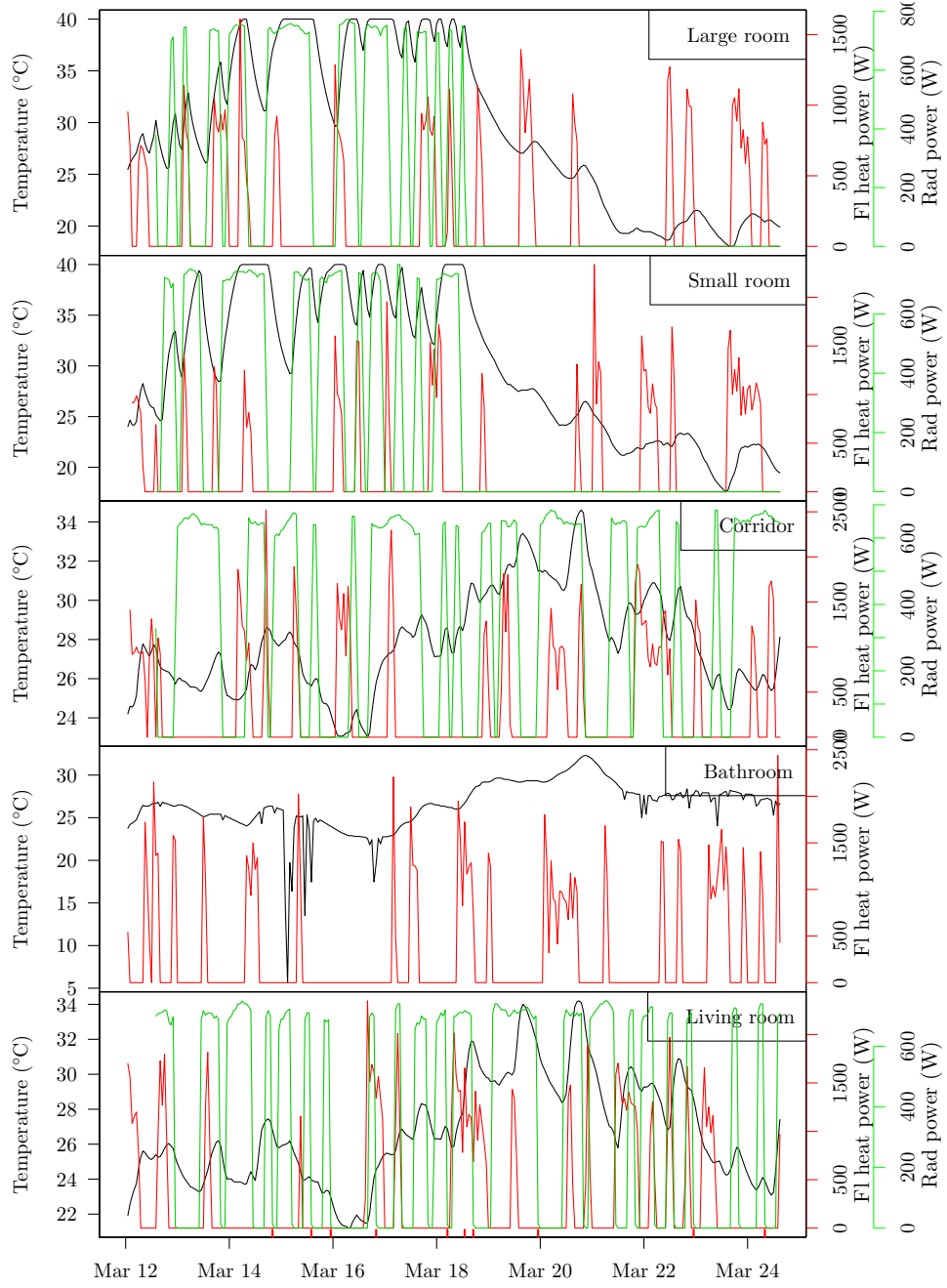


Figure 11 The heating signals and temperature measurements for the individual areas of the apartment in Experiment 5.

4 Conclusions

A new data acquisition system was installed in the low-energy house in Sisimiut in April 2011. A brief summary has been given of the data collected since related to modeling of heat dynamics of the building. 5 experiments have been carried out where the heat input has been varied. The data obtained in these experiments have been reported in more detail. Three of these experiments are intended for modeling of the guest apartment as one large room, 2 of them for multi-room models. The last experiment was with electric radiators. This enables estimation of the power capacity of the floor heating.

Some sensors seem to periodically stall. This was especially seen in the overview of all the data collected. It is advised to survey the data acquisition during experiments in order to make sure that everything works as expected.

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